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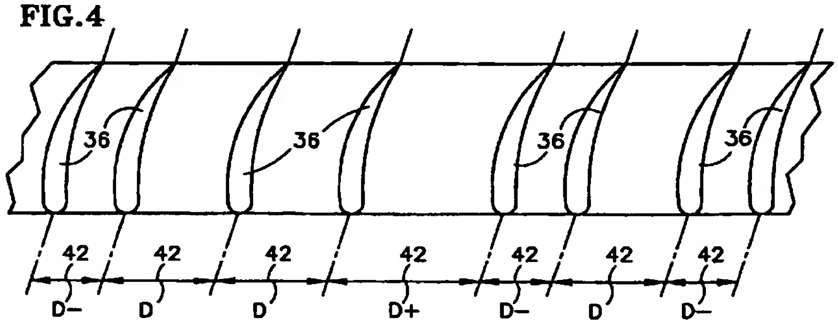
(54) Aerodynamically damping vibrations in a rotor stage of a turbomachine

(57) A rotor stage for a gas turbine engine is provided which includes a rotor disk (34) and a plurality of rotor blades (36). The rotor blades extend radially outward from the outer radial surface of the disk, and are separated from one another by a distance (D). The distance is selectively varied to increase aerodynamic damping of the rotor blades.

FIG.4



Description

[0001] This invention relates to gas turbine engine rotor assemblies in general, and to apparatus for controlling vibrations in rotor stages in particular.

[0002] Most conventional rotor stages within a gas turbine engine include a plurality of rotor blades mechanically attached to a disk for rotation around an axis. The rotor blades typically have a "fir-tree" or "dovetail" style blade root which fits into a mating slot disposed in the outer radial surface of the disk. A disadvantage of mechanically attached rotor blades is that considerable stress develops within the disk under load, adjacent the attachment slots. Increasing the disk outer diameter, and therefore the distance between adjacent slots, helps to minimize the stress. Unfortunately, increasing the disk diameter also increases the overall size and weight of the rotor stage. Recently, relatively lightweight "integrally bladed rotors" (IBR's) have become more widely used. The blades in an IBR are integrally formed (which includes blades metallurgically attached) with the disk, rather than mechanically attached to the disk. The integral blade is much more efficient at carrying the load of the blade compared to conventional mechanical attachment schemes. As a result, the size and weight of the rotor disk is advantageously minimized.

[0003] Conventional rotor stages are often tuned to avoid vibrational response and damped to minimize any vibrational response that does occur. Tuning generally refers to measures directed at changing the natural frequency(ies) of the rotor stage to avoid the frequency(ies) of periodic forcing functions present in the operating environment of the rotor stage. Damping generally refers to measures taken to minimize vibrational response caused by periodic or non-periodic (which may also be described as random) forcing functions. Periodic forcing functions operate at discrete frequencies and can cause a resonant response in the rotor blade as the frequency of the forcing function reaches unity with a natural frequency of the rotor blade. Non-periodic forcing functions, on the other hand, do not operate at a particular frequency, but rather cause the rotor blade to respond (deflect) in a non-periodic fashion. In the absence of sufficient damping, both periodic and non-periodic excitation forces can produce high blade vibratory responses for all modes of vibration present in the operating speed range.

[0004] Mechanical, aerodynamic, and material damping represent the three principal types of damping potentially of use in a rotor stage. Material damping, although occurring in conventional rotor stages and IBR's alike, is the least efficient of the three and generally will not, by itself, provide adequate damping for a rotor blade. Mechanical damping, on the other hand, is the most efficient of the three types and can be accomplished by several different methods. In one method, vibrational motion is damped by friction between a blade root and disk slot; i.e., "blade root" damping. In another method, frictional devices are externally or internally attached to a rotor blade to damp motion. In a further example, blade-to-blade shrouds are used to dissipate energy along the blade tips. These examples of mechanical damping are not, however, practical with most IBR's because of the integral nature of the IBR blades. Separate damper devices between IBR rotor blades and the disk or devices between adjacent IBR rotor blades are not practical either.

[0005] Aerodynamic damping generally refers to the exchange of work between the rotor stage and the air passing through the rotor stage. If the net work done by the air on a rotor blade, for example, exceeds the work done by the rotor blade on the air, then the air adds energy to the blade. This reflects an unstable condition, where blade oscillations can begin and/or increase in magnitude and ultimately result in fatigue. On the other hand, if the net work done by a rotor blade on the air exceeds the work done by the air on the rotor blade, then the rotor blade dissipates energy into the airflow. This transfer of energy away from the rotor blade reflects the desirable condition of aerodynamic damping.

[0006] Hence, what is needed is apparatus and/or a method for damping vibrational responses in a rotor stage, one that may be used in an IBR, one that damps periodic forcing functions and non-periodic (random) perturbations, and one that effectively damps vibrations in moderate and low aspect rotor blades.

[0007] According to a first aspect of the present invention, a rotor stage for a gas turbine engine is provided which includes a rotor disk and a plurality of rotor blades. The rotor blades extend radially outward from the outer radial surface of the disk, and are separated from one another by a distance. The distance is selectively varied to increase aerodynamic damping of the rotor blades.

[0008] Viewed from a second aspect, the present invention provides a rotor stage for a gas turbine engine, comprising a rotor disk having a plurality of rotor blades extending radially outward from, and distributed around, the outer radial surface of the rotor disk, the circumferential length of the outer radial surface of the rotor disk divided by the number of rotor blades defining a uniform inter-rotor blade distance, wherein at least a pair of adjacent rotor blades are separated by a distance which is either less than or greater than, but not equal to, the uniform inter-rotor blade distance.

[0009] From an aerodynamic damping point of view, energy transmitted to the rotor blades may be described as unsteady work done by the blade on the air passing by the blade during a cycle of oscillation, using the following mathematical expression:

$$\phi\int\tilde{P}(x,y,z,t)\cdot W(x,y,z,t)dAdt$$

where $\tilde{P}$ (x,y,z,t) represents the difference in unsteady air pressure acting on the suction and pressure side

surfaces of the rotor blade at any point as a function of time as a result of the blade undergoing a vibratory motion, and W(x,y,z,t) represents the deflection of the rotor blade in any direction as a function of time. The work expression is integrated over time period "T", where "T" equals the time duration of one blade oscillation. Positive work per cycle (indicated by a positive value of the work expression) describes work being done on the blade by the passing air; i.e., an unstable condition. Negative work per cycle (indicated by a negative value of the work expression) indicates that work is being done by the blade on the passing air; i.e., the desirable condition of aerodynamic damping. A zero value of the work expression is referred to as a neutral condition; i.e., the blade is neither receiving nor doing work.

[0010] Because the goal of aerodynamic damping is to damp a given mode of vibration, one can assume that the deflection term (W(x,y,z,t)) in the above equation can be considered a non-variant. Aerodynamic damping can be achieved, therefore, by manipulating the unsteady pressure variable ($\tilde{P}$ (x,y,z,t)) to ensure work is being done by the blade as opposed to being done on the blade. The difference in unsteady pressure acting on the rotor blade is a function of : 1) the air passing the rotor blade; 2) the volume of air between adjacent rotor blades; and 3) the relative motion of the adjacent blades. In the present invention, the volume of air between adjacent rotor blades is being manipulated by selectively varying the distance between rotor blades.

[0011] Thus, viewed from a third aspect, the present invention provides a method of damping vibrations in a rotor stage for a gas turbine engine which comprises a rotor disk having a plurality of rotor blades extending radially outward from, and distributed around, the outer radial surface of the rotor disk, wherein the distance between at least two adjacent rotor blades is selectively varied to increase aerodynamic damping of the rotor stage.

[0012] An advantage of the present invention is that a means for aerodynamic damping is provided. In some applications, aerodynamic damping can be used to augment mechanical and/or material damping. In other applications where mechanical and/or material damping is limited (e.g., an IBR), aerodynamic damping can be provided as a principle means of damping.

[0013] Another advantage of the present invention is that rotor stage damping apparatus is provided that is effective against vibrations caused by periodic forcing functions and non-periodic perturbations. The selective rotor blade spacing of the present invention enables the rotor blades to do work on the air passing the rotor blade, regardless of whether the blade is subject to a periodic forcing function or a non-periodic perturbation.

[0014] Another advantage of the present invention is that vibrations in moderate and low aspect ratio rotor blades can be effectively damped. Moderate and low aspect ratio rotor blades, conventionally attached or integrally formed, are particularly susceptible to chordal modes of vibration. The selective rotor blade spacing of the present invention enables the rotor blades to damp deflections caused by periodic and non-periodic perturbations of fundamental as well as complex chordal modes of vibration.

[0015] Another advantage of the present invention is that it does not require additional hardware, internal blade machining, or the like. Rather, the present invention provides damping by selectively spacing the rotor blades around the outer radial surface of the rotor disk. A person of skill in the art will recognize that simplicity generally equates to reliability.

[0016] A preferred embodiment of the present invention will now be described by way of example only and with reference to the accompanying drawings, in which:

FIG. 1 is a diagrammatic sectioned view of a gas turbine engine;
FIG. 2 is a diagrammatic perspective partial view of a prior art gas turbine rotor stage;
FIG. 3 is a diagrammatic perspective partial view of a gas turbine rotor stage; and
FIG. 4 shows a linear representation of rotor blades extending out from a rotor disk to illustrate inter-blade spacing.

[0017] Referring to FIG. 1, a gas turbine engine 10 includes a fan 12, a low pressure compressor 14, a high pressure compressor 16, a combustor 18, a low pressure turbine 20, a high pressure turbine 22, an augmentor 24, and a nozzle 26 symmetrically disposed relative to an axis of rotation 28. The fan 12 is forward of the nozzle 26 and the nozzle 26 is aft of the fan 12. The fan 12 and the low pressure compressor 14 are connected to one another and are driven by the low pressure turbine 20. The high pressure compressor 16 is driven by the high pressure turbine 22. Air worked by the fan 12 will either enter the low pressure compressor 14 as "core gas" or will enter a passage 30 outside the engine core as "bypass air".

[0018] Referring to FIGS. 2-4, a rotor stage 32 includes a disk 34 and a plurality of rotor blades 36. The disk 34 includes a bore 38 (FIG. 3) centered on the axis of rotation 28 and an outer radial surface 40. The rotor blades 36 extend radially outward from the outer radial surface 40 and may be attached to the disk 34 via conventional attachment methods (e.g., fir tree or dovetail root - not shown) or may be integrally attached as a part of an integrally bladed rotor (IBR).

[0019] In a conventional rotor stage 32 (FIG. 2), the rotor blades 36 are equally spaced apart from one another by a distance "D" equal to the circumferential length of the disk outer radial surface 40 divided by the number of rotor blades 36 (i.e., "D" represents the distance between the centerlines of adjacent rotor blades). In the present invention (FIGS. 3 and 4), the distance 42 between adjacent rotor blades 36 (i.e., the "inter-rotor

blade" distance) is selectively varied to achieve an increase in aerodynamic damping. The amount each inter-rotor blade distance 42 is varied, if at all, depends upon the application at hand. In terms of the uniform inter-rotor spacing distance "D", the distance 42 between adjacent rotor blades 36 is typically no less than eighty percent of the uniform spacing value (.80D) and no greater than one hundred and twenty percent (1.20D) of the uniform value "D". The inter-rotor blade distance 42, however, is preferably between eighty-five and ninety-five percent of the uniform spacing value (.85D - .95D) or between one hundred and fifteen and one hundred and five percent (1.15D -1.05D) of the uniform spacing value "D". The optimum distance 42 between adjacent rotor blades 36 (and therefore the optimum damping) is a function of the circumstances of the application, and can be determined analytically or empirically. FIG. 4 diagrammatically illustrates the selectively varied spacing by showing inter-rotor blade distances equal to "D", "D-", or "D+", where "D" represents the aforementioned uniform inter-rotor blade distance, "D-" represents a distance less than "D", and "D+" represents a distance greater than "D".

[0020] In some applications, a majority of the rotor blades 36 are uniformly spaced a distance "D" from one another, and only a few rotor blades 36 are non-uniformly spaced relative to adjacent rotor blades 36. In other applications, a majority or all of the inter-rotor blade distances 42 will be non-uniform. For balance purposes, however, it is preferable to have symmetry between rotor disk 34 halves with respect to rotor blade 36 spacing. For example, if a first blade is shifted a distance to the left of its uniform spacing position, then a second blade normally located 180° away from the first blade, is preferably shifted from its uniform spacing position by that same amount to the right; i.e., the rotor blades remain 180° offset from one another.

[0021] Thus, it will be seen that at least in the illustrated embodiments, the present invention provides a rotor stage for a gas turbine engine that includes apparatus for damping vibrations; which may be used for damping vibrations in an IBR; which is effective against vibrations caused by periodic forcing functions and non-periodic perturbations; and which effectively damps vibrations in moderate and low aspect ratio rotor blades.

[0022] Although this invention has been shown and described with respect to the detailed embodiments thereof, it will be understood by those skilled in the art that various changes in form and detail thereof may be made without departing from the scope of the invention as defined by the claims. For example, under some circumstances it may be desirable to have an inter-rotor blade distance less than .80D, or an inter-rotor blade distance greater than 1.20D.

Claims

1. A rotor stage for a gas turbine engine, for rotating around an axis of rotation, comprising:

   a rotor disk (34) having an outer radial surface (40), said outer radial surface having a circumferential length;

   a plurality of rotor blades (36), extending radially outward from said outer radial surface, wherein adjacent said rotor blades are separated from one another by an inter-rotor blade distance (D,D-,D+), and wherein said inter-rotor blade distances are selectively varied.

2. A rotor stage for a gas turbine engine according to claim 1, wherein said selectively varied inter-rotor blade distances (D-) are at least eighty percent of a uniform inter-rotor blade distance (D).

3. A rotor stage for a gas turbine engine according to claim 2, wherein said selectively varied inter-rotor blade distances (D-) are at least eighty-five percent of said uniform inter-rotor blade distance (D).

4. A rotor stage for a gas turbine engine according to claim 3, wherein said selectively varied inter-rotor blade distances (D+) are no more than one hundred and twenty percent of laid uniform inter-rotor blade distance (D).

5. A rotor stage for a gas turbine engine according to claim 4, wherein said selectively varied inter-rotor blade distances (D+) are no more than one hundred and fifteen percent of said uniform inter-rotor blade distance (D).

6. A rotor stage for a gas turbine engine according to any preceding claim, wherein at least one of said inter-rotor blade distances (D) is selectively varied.

7. A rotor stage for a gas turbine engine according to any preceding claim, wherein a plurality of said inter-rotor blade distances (D) are selectively varied.

8. A rotor stage for a gas turbine engine according to any preceding claim, wherein a majority of said inter-rotor blade distances (D) are selectively varied.

9. A rotor stage for a gas turbine engine according to any preceding claim, wherein each of said rotor blades (36) is 180° offset from another one of said rotor blades.

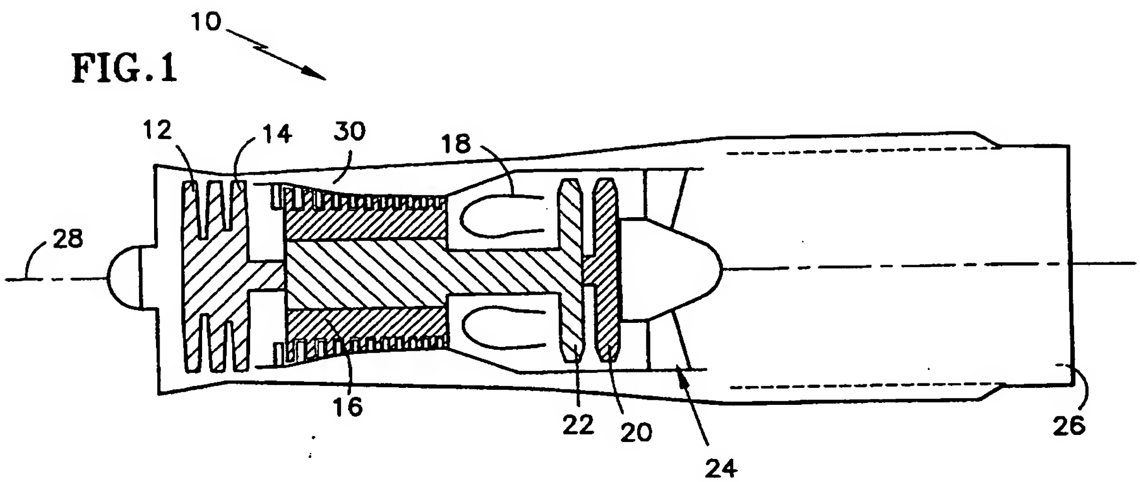
10. A rotor stage for a gas turbine engine according to any preceding claim, wherein said rotor disk (34) and rotor blades (36) are an integrally bladed rotor.

11. A rotor stage for a gas turbine engine, comprising a

rotor disk (34) having a plurality of rotor blades (36) extending radially outward from, and distributed around, the outer radial surface of the rotor disk, the circumferential length of the outer radial surface of the rotor disk divided by the number of rotor blades defining a uniform inter-rotor blade distance (D), wherein at least one pair of adjacent rotor blades are separated by a distance which is either less than or greater than, but not equal to, the uniform inter-rotor blade distance (D).

12. A method of damping vibrations in a rotor stage for a gas turbine engine which comprises a rotor disk (34) having a plurality of rotor blades (36) extending radially outward from, and distributed around, the outer radial surface of the rotor disk, wherein the distance (D) between at least two adjacent rotor blades is selectively varied to increase aerodynamic damping of the rotor stage.

FIG.1



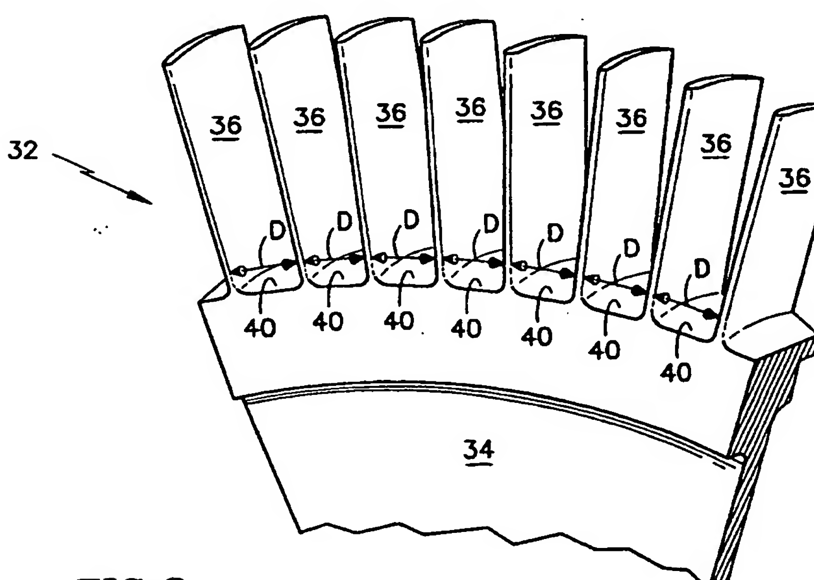


FIG.2
prior art

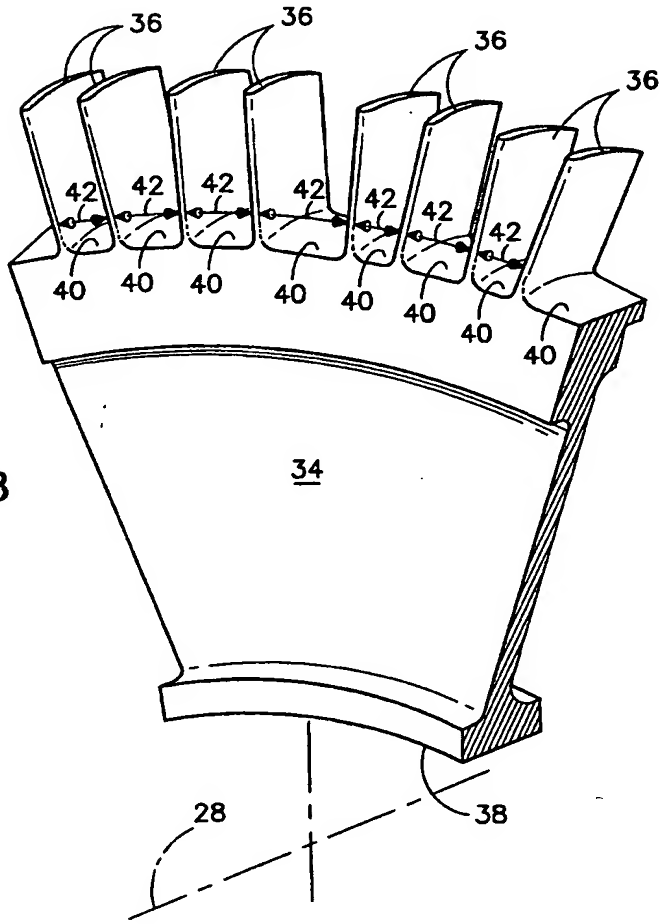

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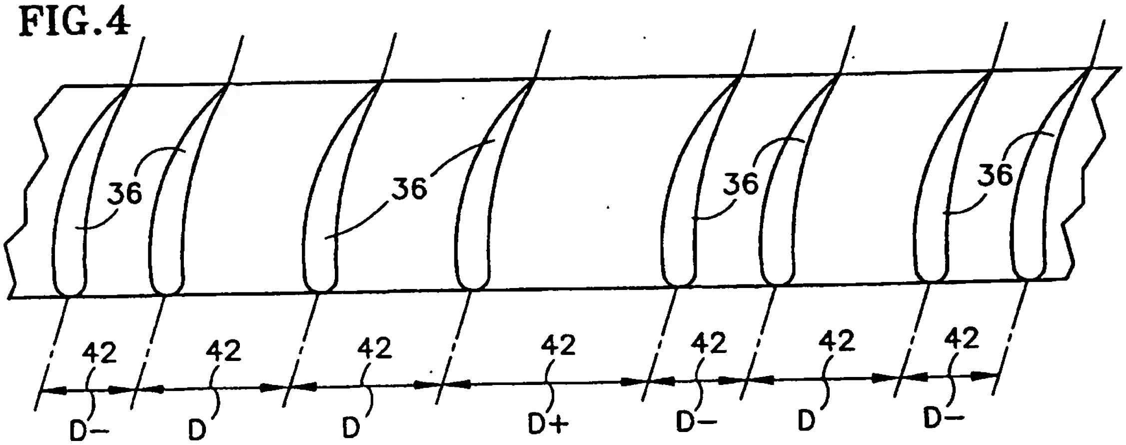
FIG.3

FIG.4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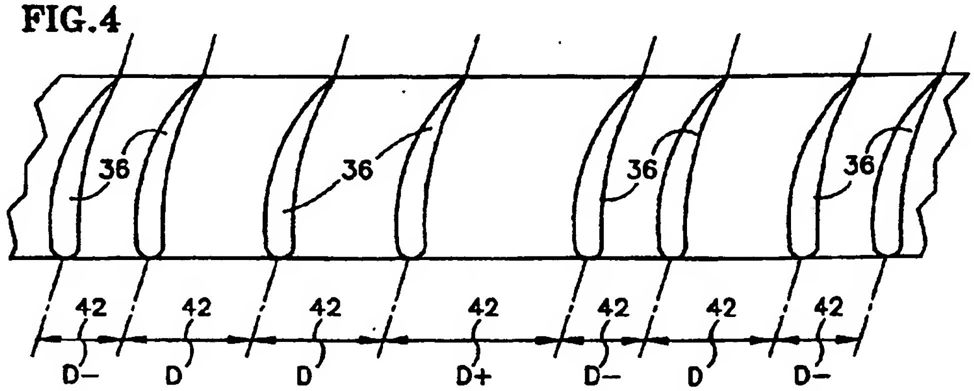

EP 0 921 274 A3

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EUROPEAN SEARCH REPORT

Application Number
EP 98 30 9906

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The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	6 July 2000	Raspo, F

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EUROPEAN SEARCH REPORT

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EP 98 30 9906

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Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
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